National Aeronautics and
Space Administration

Dynamic CFD Simulations of the Supersonic Inflatable Aerodynamic Decelerator (SIAD) Ballistic Range Tests

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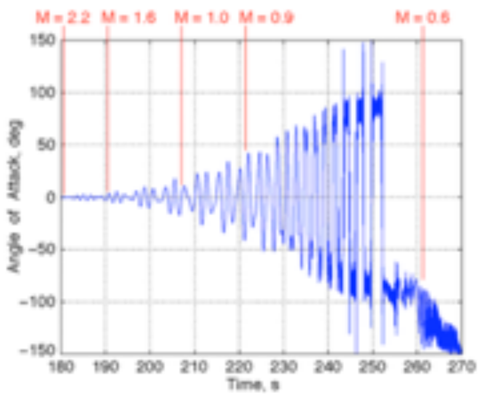
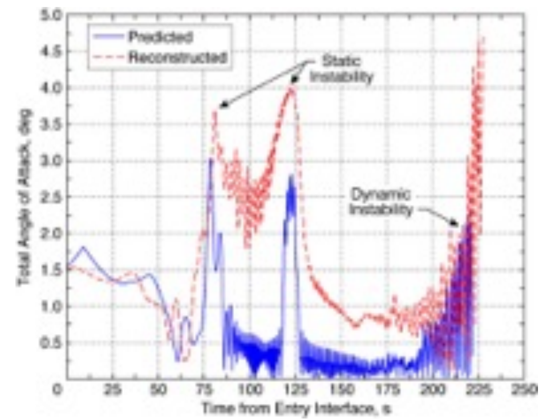
Blunt Body Dynamic Stability

Genesis Sample Return Capsule (Desai, 2008)



Mars Phoenix Lander (Desai, 2011)

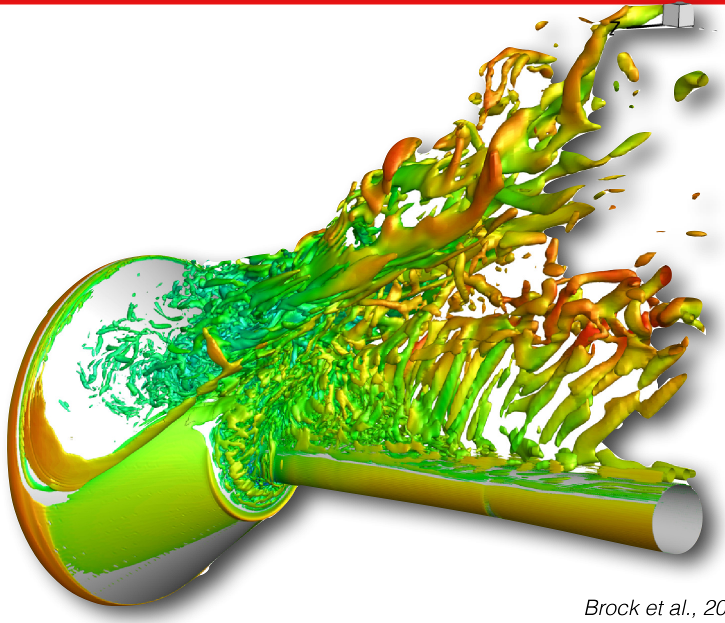


- Blunt-body capsules are very effective at reducing heating to the surface
- Dynamic instabilities often arise at low-supersonic and transonic Mach numbers
- Dynamic stability is characterized exclusively through experiment — forced-, free-oscillations, and ballistic range — however each has drawbacks resulting in uncertain predictions
  - In all cases, flight similitude parameters are difficult to achieve

- CFD is an integral part of *static* aerodynamic characterization and design.
- Would be desirable to have similar capability for *dynamic* aerodynamics

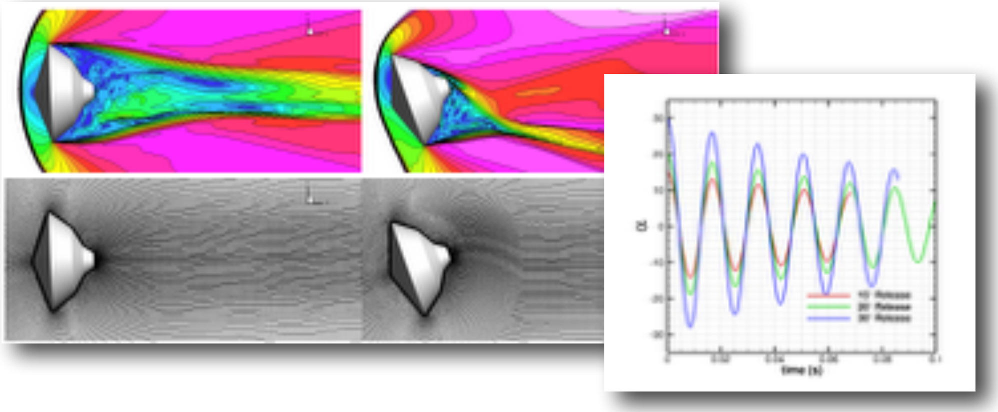
US3D Dynamic Solver

- Murman performed dynamic CFD using OVERFLOW(2009)
- Unsteady wake dynamics considered strong influence on dynamic stability
- Low-dissipation numerical schemes in US3D have been shown to provide greater resolution of wake flows
- Stern *et al.* demonstrated proof-of-concept for US3D dynamic solver simulating an MSL ballistic range



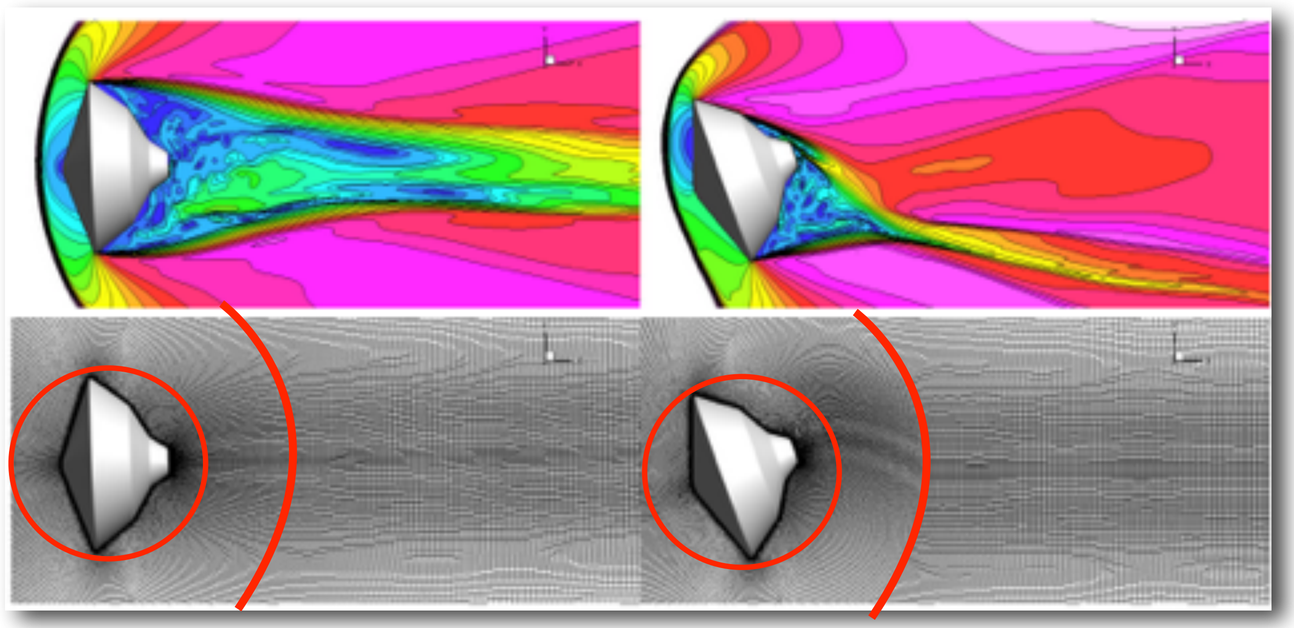
Brock et al., 2014

Current work seeks to begin to validate this approach in supersonic regime through the comparison to experimental data from ballistic range



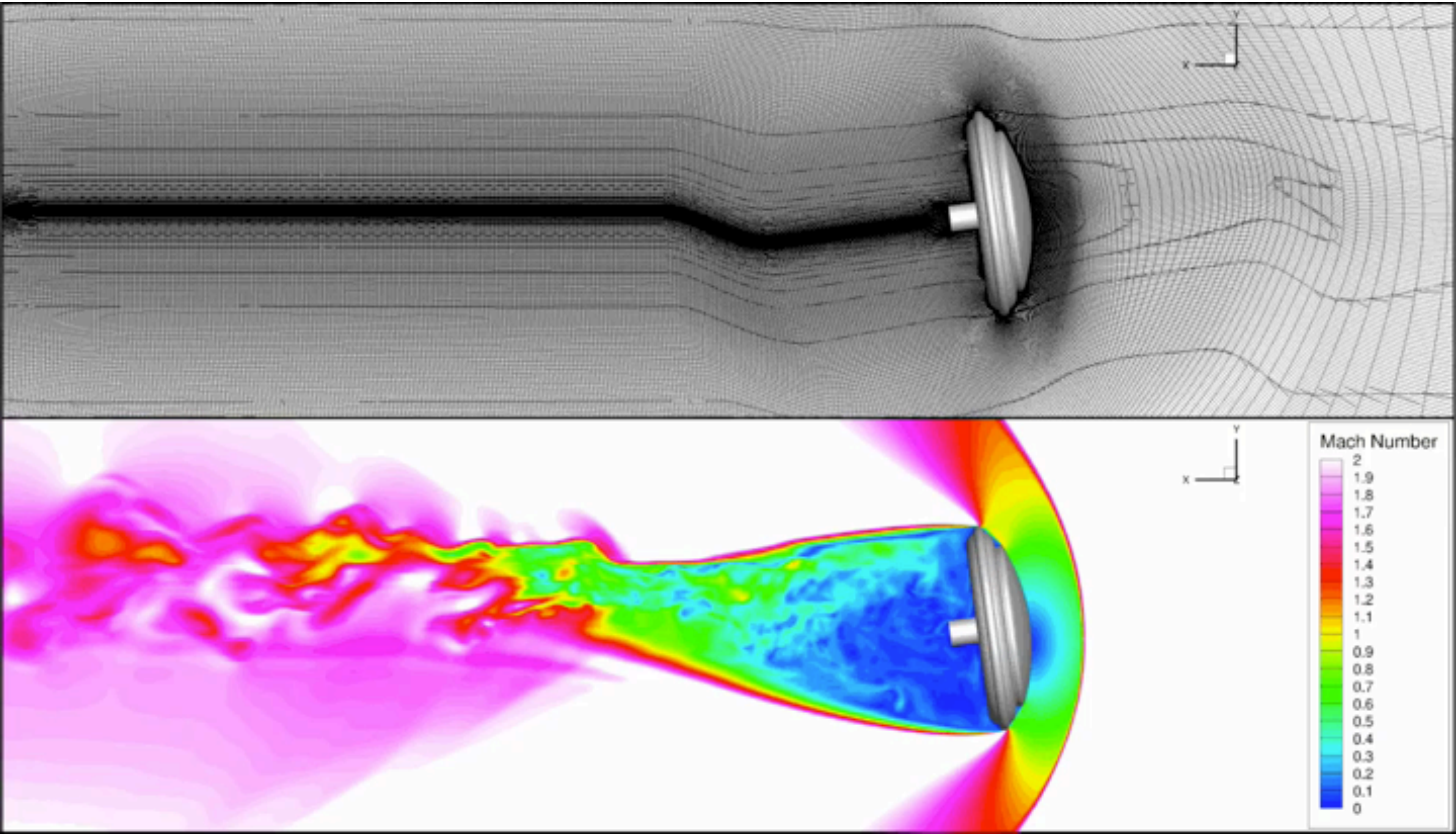
Stern et al., 2013

US3D Dynamic Solver

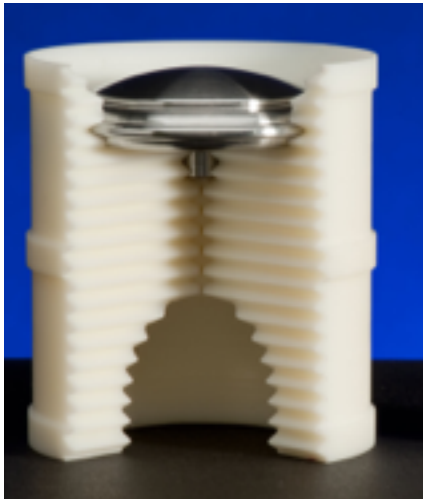


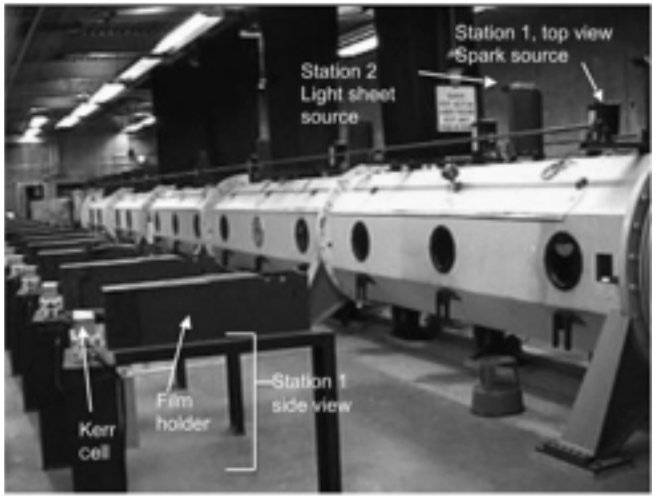
- US3D requires body-fitted mesh
- Mesh deformation employed to model 3-DOF (pitch, yaw, roll) motion
    - Inner mesh undergoes rigid body rotation with vehicle
    - Intermediate region blends inner rigid body rotating mesh to outer static region by interpolating node displacements
- Frame velocity applied to discrete governing equations when translation dynamics (i.e. acceleration, deceleration) are required

Dynamic CFD Modeling



Supersonic Flight Dynamics Test (SFDT)





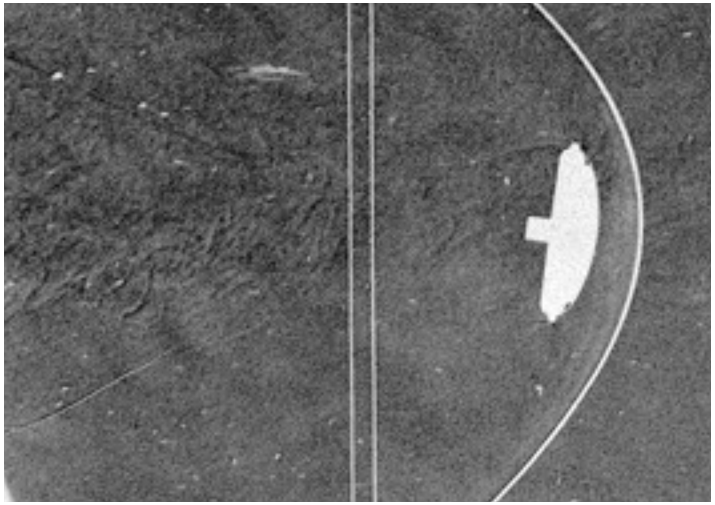
Bowes et al., 2015

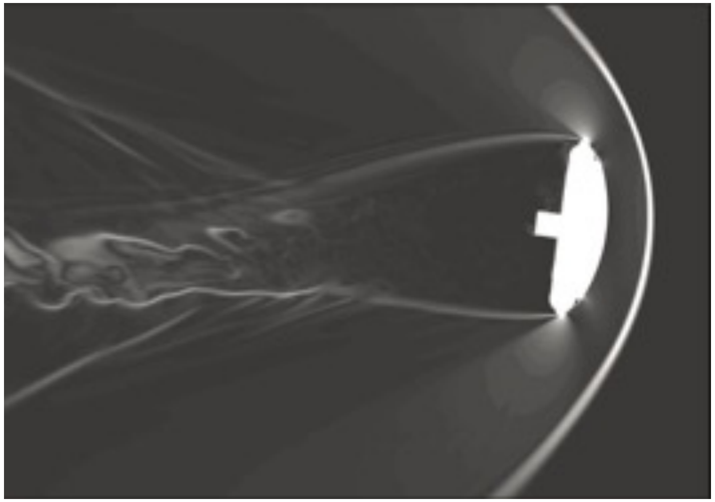
- Low Density Supersonic Decelerator (LDSD) project conducted two separate full scale Supersonic Flight Dynamics Tests (SFDT) of the Supersonic Inflatable Aerodynamic Decelerator (SIAD) concept
- A series of ballistic ranges tests was performed in the Hypervelocity Free-Flight Aerodynamics Facility (HFFAF) located at the NASA Ames Research Center (ARC)
    - Data provided dynamic stability coefficients of scaled model
- Test model is a scaled representation of the SIAD geometry in the deployed configuration from the SFDT test series
- Ballistic range provides full 6-DOF data
    - Data is averaged over several shots and then reduced to aerodynamic coefficients

Flow Initialization

- The simulation is initialized at static orientation of first experimental data point
  - This potentially misses vehicle-wake coupling at start up
- The simulation continues until the flow is converged to pseudo-steady state
  - Unsteady fluctuations of wake are statistically converged
- Comparison of density gradient magnitude from the simulation to shadowgraph images of the experiment show excellent qualitative agreement of dominant features

Run	Average Mach
Shot 2623	2.01

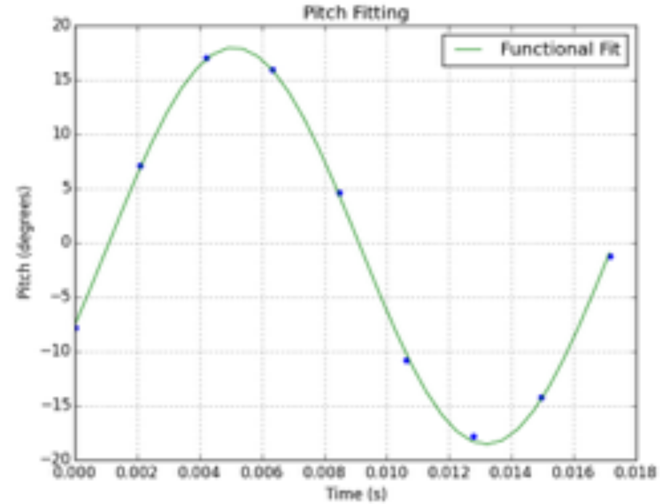


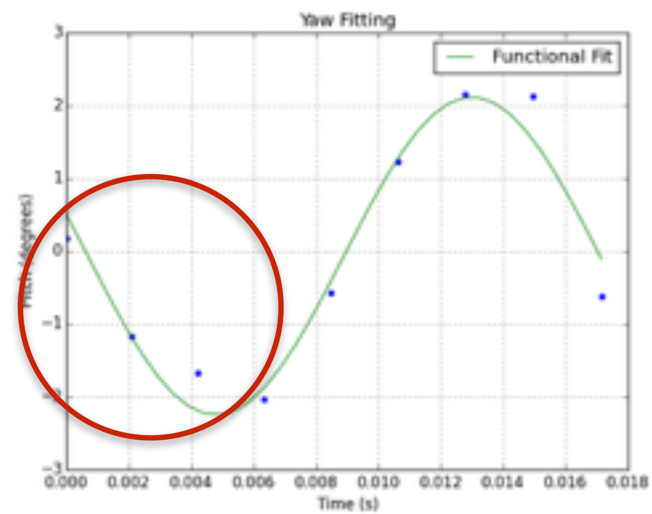


Dynamic Simulation Startup

- Initial rates are taken from experimental data and applied to geometry
  - First derivative of a cosine functional fit at first data point
    - ➢ Derivative will be applied as a rotation rate to the mesh deformation
  - Some fits are poor due to rapid growth in oscillation of experiment or potential error in measured angle
    - ➢ Typically seen for small angles
  - Poor rate fits are instead approximated using linear derivative evaluation between first and second data point
    - ➢ Potential source of error

Run	Average Mach
Shot 2623	2.01

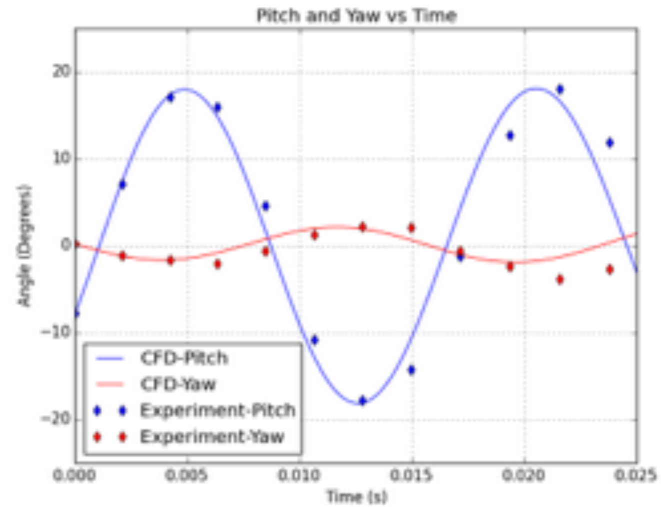


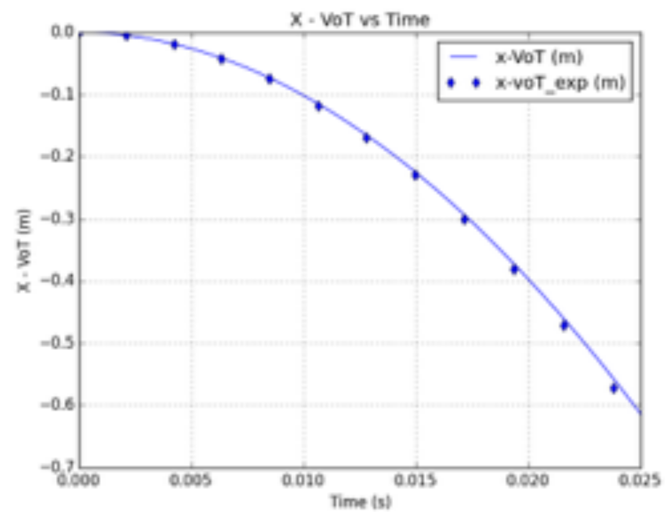


Dynamic Data

- Simulation data for pitch, yaw, and downstream distance is compared against experimental data
  - Oscillation amplitude of simulation matches very well against experiment
  - Slight increase in oscillation frequency for simulation is seen compared to experiment
    - ➢ May be due to artificial initial condition
  - Predicted downstream distance shows excellent agreement with experimental data
    - ➢ Results is dominated by drag prediction

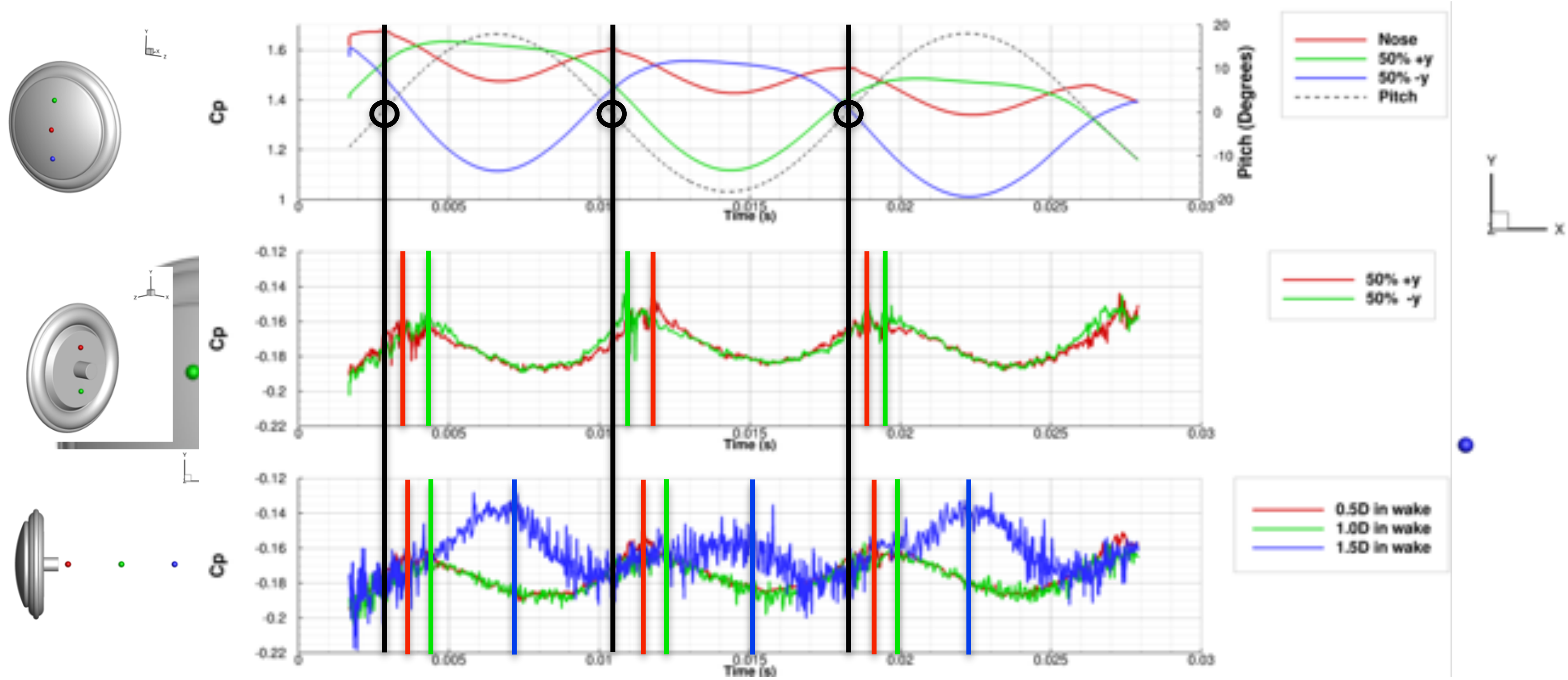
Run	Average Mach
Shot 2623	2.01





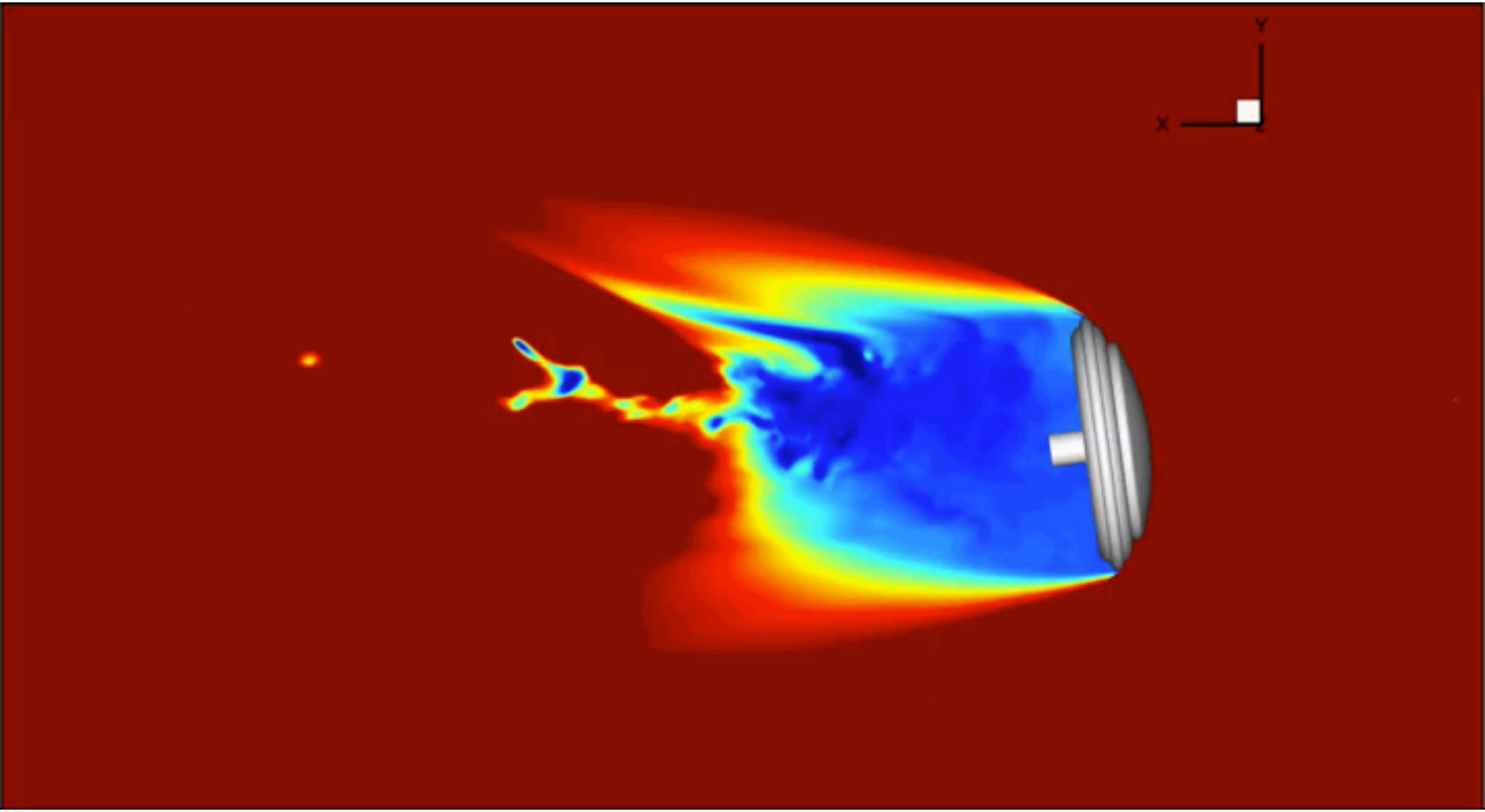
Interrogation of Flow Physics

- An advantage of CFD is the capability to probe flow physics at various regions for minimal to no additional cost
  - Analysis of fluid dynamics and interaction that drive dynamic (in)stability
- Several pressure probes were placed on vehicle surface and in near wake of vehicle
- Time-history data of pressure coefficient show lag in wake pressure response compared to forebody
  - Lag has been previously stated as a mechanism of instability by Teramoto *et al.*

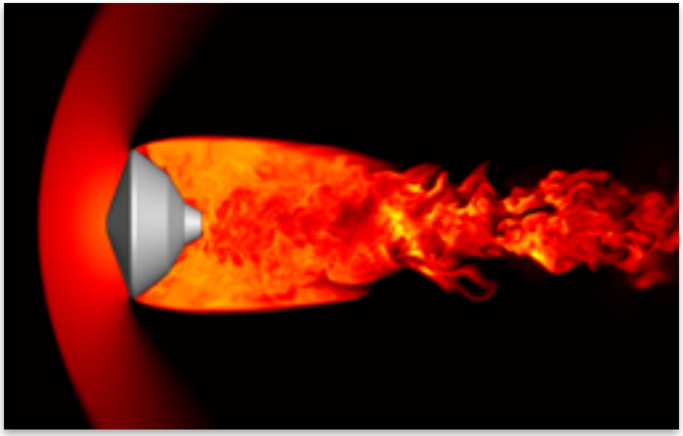


Wake Flow Pressure

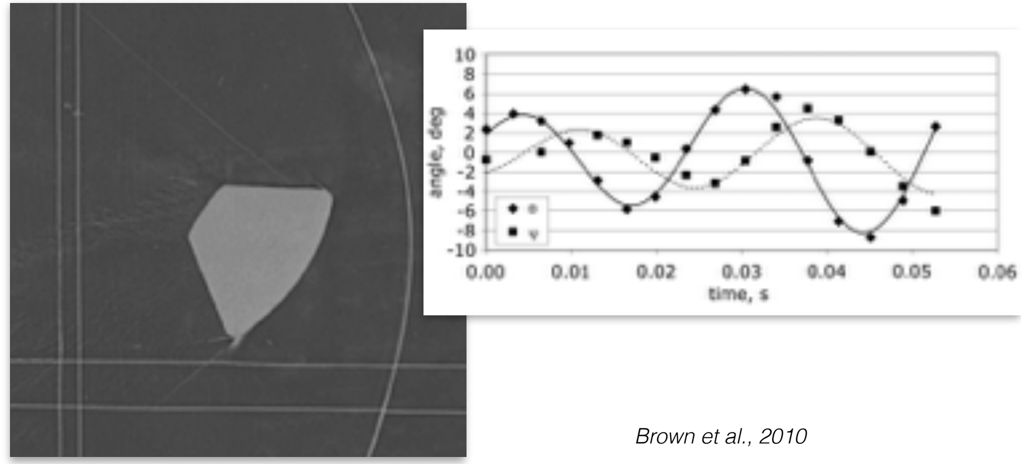
Run	Average Mach
Shot 2623	2.01



Future Work



Stern et al. (upcoming)



Brown et al., 2010

- Continue validation/verification of US3D as a computational tool to predict dynamic stability within supersonic regime
  - Investigate artificial startup conditions and their consequences on long-time dynamic behavior
  - Compare flight scale simulation against reconstructed flight data
  - Further investigate physical mechanisms
- Wider range of supersonic cases
- Subsonic/transonic experimental data

Acknowledgements

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